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Making Infrastructure Procurement Processes more Flexible under Uncertainty

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COVER PAGE

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ABSTRACT

A third to a half of development projects undergo restructuring due to changes in project objectives, scope or other unanticipated changes, therefore requiring schedule extensions, budget additions and rework. Current procurement processes discourage managers from responding strategically by anticipating and preparing for such changes in advance through better information search and design concept evaluation. This paper suggests three principles for making the front-end phases of procurement more flexible - understanding uncertainty, studying system-wide impacts, and phasing designs. A case study analysis of urban water system design in Kabul demonstrates the conceptual and analytical application of these principles.

Keywords: infrastructure, procurement, uncertainty, system design, South Asia, Afghanistan

1. INTRODUCTION

This paper focuses on the front-end, early stage design phases of infrastructure procurement. Procurement is the overall process by which the public sector installs infrastructure assets or secures provision of infrastructure-related services. Stakeholders shape infrastructure project objectives, scope, and high-level design concepts in the front-end stages of procurement (Lessard and Miller, 2013; Merrow, 2011).

Projects often witness changes or redefinitions in objectives or scope as needs are better identified, feasibility is assessed, stakeholder preferences evolve, or unanticipated changes in economic or social contextual factors materialize (de Neufville and Scholtes, 2011). The analysis in this paper estimates that a third to a half of all development projects undergo some form of restructuring in the later stages of procurement. The fraction of restructuring instances is possibly larger for infrastructure projects. Schedule delays, budget overruns, contractual renegotiations and vicious cycles of rework may typically accompany restructuring.

This paper argues that development institutions should fundamentally alter their perspective to procurement, by anticipating restructuring and designing flexible procurement processes. Flexibility is the ability to update, defer, or abandon design decisions as uncertainties are resolved, or at least until better information is available (de Neufville & Scholtes, 2011). Flexible procurement is valuable because of the avoided costs of time, effort, delays and stakeholder frictions in the face of deep uncertainty and unanticipated changes.

Flexibility in procurement can be especially valuable in highly uncertain infrastructure delivery programs such as Economic or Resource Corridor Programs. An “economic corridor” in development is defined as a sequence of decisions to leverage a number of sites of significant investment and economic activity for the viable development of a broader geographic area. When the investments are mining or oil & gas projects, the programs may be called Resource Corridor Programs (RCPs). Such programs often include

supporting infrastructure projects in water, power and transportation that serve as the backbone for the other target activities. RCPs can be highly uncertain decision-making environments because they evolve over decades and face risks such as unpredictable demand growth, volatile global commodity prices, and changing political and social climate.

This paper uses flexibility as a lens to examine two related aspects of the front-end procurement process – information search and concept evaluation. The first involves how project managers uncover information about many different conceptual design options and their implications. We recommend that managers simultaneously conduct preliminary design, feasibility and environmental impact studies on a wide range of conceptual design options, since these studies entail about 1 – 2% of the final cost of procuring infrastructure. The information obtained enables better decision-making in later stages of procurement at little up front cost. While the recommendation may seem straightforward in principle, in practice managers often find their hands tied because of standardized organizational processes in project appraisal and budgeting. This information search and acquisition is a kind of minimum requirement for remaining flexible, and may justify changes to the standardized procurement process.

The second aspect is about how project managers evaluate and select from different conceptual designs. Here we recommend that managers adopt a systems perspective by evaluating projects in terms of contribution to overall system performance, instead of as stand-alone ventures. The paper demonstrates the recommended analytical process through a case study of an urban water system design effort for the city of Kabul, Afghanistan. This water system project is intimately connected with a copper mining venture in the Afghanistan Resource Corridor Program that consists of mining, water, power and transportation projects and faces high demand uncertainty.

A simple example illustrates both the information search and concept evaluation issues. Consider a program of infrastructure investments involving Project A: Transmission Line and Project B: Power Plant. These projects are interdependent: the power plant is useful only when its power can be transmitted, and the line is useful when there is power to transmit. Among many possible design variants for each, assume

that both A and B can be of only two types, small or large (for the power plant) and low or high capacity (for the transmission line). While the high capacity transmission line can feasibly transmit power from either a small or large plant, the low capacity line is suitable only for the small power plant. The fundamental uncertainty affecting these design choices is the amount of power that will be needed, which further depends on economic growth in the region. Selecting the small designs may result in a missed opportunity if demand turns out to be high, whereas large projects may be underutilized if demand turns out to be low. Decision-makers are under pressure to select design concepts, so that the project can move on to phases of budgeting and approval, and detailed design and construction. Which combination of the design variants should they select, and how should they make this choice? Decision-makers typically use experience and intuition to select the “better” one for further exploration. However, the judgment in this example is subject to uncertainty – the scenario or “state of the world” that eventually unfolds determines the better concept. On the first issue of information search, managers should remain flexible by conducting feasibility, preliminary design and environmental impact studies on both design variants in their choice set for projects A & B, before selecting one or more for final budgeting and approval. The cost of additional feasibility studies is miniscule compared to the stranded cost of assets that are held up or abandoned because they are a poor solution to the needs that actually materialize. On the second issue of concept evaluation, managers should evaluate combinations of design variants under simulated uncertain demand, for instance a small power plant and a large transmission line taken together as a system, instead of evaluating each project separately. The combination of a small plant and large transmission line may be more valuable under uncertainty relative to other combinations because it can be a cost-effective solution in cases of low demand, and also allows for additional generation capacity to be added in cases of high demand without the cost of building additional transmission lines. Thus, managers can identify available real options by using a systems perspective to evaluating combinations of variants.

Project managers who undertake development projects in highly uncertain environments may find immediately useful our recommendation to remain flexible during the phases of information search. Managers and policy-makers of significant infrastructure undertakings, such as Resource Corridor

Programs, should find both the perspective on information search and the analytical process of concept evaluation under uncertainty applicable to their efforts.

The structure of the paper is as follows. Section 2 discusses the procurement process including challenges, concepts and the need for flexibility in applications such as Resource Corridor Programs. This section also presents observations from the literature and descriptive statistics on restructurings in procurement in World Bank projects. Section 3 presents three general principles for how information search and concept evaluation in procurement can result in phased flexible design strategies. Section 4 demonstrates the conceptual and Monte Carlo-based analytical application of these principles in an urban water system design study. Finally, Section 5 discusses the implications of our proposal and offers concluding remarks.

2. INFRASTRUCTURE PROCUREMENT

This section describes some challenges that make infrastructure procurement difficult. It also conceptualizes the procurement process and discusses the traditional and flexible approaches to procurement. Finally, it presents some evidence on the need for flexibility in the procurement process.

(a) Challenges in infrastructure procurement

Infrastructure planning and procurement is a major activity for policymakers, planners, and financiers, and has long been a strategic priority in almost all development organizations (World Bank, 1994; Tan 2012). Infrastructure assets and related services provide a backbone for the functioning of modern economies (O'Rourke, 2007). Economic growth is often the motivating driver for infrastructure development, although estimates of its economic impact (Aschauer 1989a, 1989b; Barro, 1990; Sanchez-Robles, 1998), and the direction of causality between infrastructure and economic growth remain controversial (Esfahani and Ramirez, 2003, Easterly and Serven, 2003; Fedderke and Bogetic, 2009; Candelon et al, 2012). Governments covet stable, well developed, and functioning infrastructure systems, but these often remain elusive for a number of reasons. Many attribute infrastructure project failures to optimistic demand forecasts, weak home institutions, immature markets, and opportunistic firms and governments (Flyvbjerg

et al, 2003; Gómez-Ibáñez, 2003). The pitfalls of relying on forecasted needs for infrastructure are particularly relevant to our arguments (Flyvbjerg et al., 2005; Kahneman et al, 2011).

Large infrastructure projects such as power plants, ports, and multi-purpose hydro developments are generally difficult endeavors because of their long-term implications, economic and financial risk, and interdependencies with other service systems or sectors. Often requiring hundreds of millions to billions of dollars, infrastructure projects can intimidate governments and private firms. They are not only expensive, but can also have a huge opportunity cost and draw valuable resources away from other worthy activities.

Since infrastructure projects are long-lived technically, the legacy nature of infrastructure becomes an important determinant in the scope for new projects. Many projects are “relationship-specific” – they are designed with very specific end-uses in mind at particular locations and cannot be redeployed at other locations or for other uses (Williamson, 1975; Hart 1998, Joskow 1988). Over time, existing systems constrain or narrow the scope of what can be built in the future. For instance, a new power plant is useful only if there exists transmission capacity to deliver the generation output to load centers. In the absence of a suitable transmission grid for off-take, the inherent value of the plant and its usefulness is much reduced. In this example, the interdependency between power plants (“generation”) and the high-voltage grid (“networks”) implies constraints for the output capacity, technology and siting of new power projects.

The long economic life of infrastructure means that revenues occur over decades. Sponsors spend capital in the front-end development and construction phases of projects, but receive benefits after commissioning and during stable operation. The viability of projects can be sensitive to the volatility in prices of key inputs such as fuel or other input goods and commodities. Although these risks can be managed in a variety of ways, not all risks can be mitigated or diversified away and continue to reside in the infrastructure project (Miller and Lessard, 2001b). The longer the time over which benefits must accrue to make a project viable, the greater are its economic risks.

While there are many different approaches to the design, risk management, financing and governance of infrastructure for development (Swaroop, 1994; Dailami and Leipziger, 1998; Gomez-Ibanez, 2003;

Grimsey & Louis, 2005; Tan, 2012), they do not directly address project design issues encountered in the front-end phases of the procurement process, before financial closure has been reached or contracts have been written. This paper focuses on conceptual design in the front-end phases.

(b) Perspectives on procurement

This section presents a conceptual overview of the front-end stages of the infrastructure procurement process. It also compares and contrasts a stylized “traditional” approach to procurement with a “flexible” approach.

Figure 1 shows the typical sequence of front-end phases of procurement. The horizontal axis, ‘level of escalation’, indicates the extent to which capital has been committed in any phase of procurement. The vertical axis, ‘degree of commitment/lock-in’, indicates the specificity of the chosen project design in the corresponding phase of procurement. Figure 1 thus relates the degree of lock-in in various procurement phases to the consequences of escalating and abandoning the project.

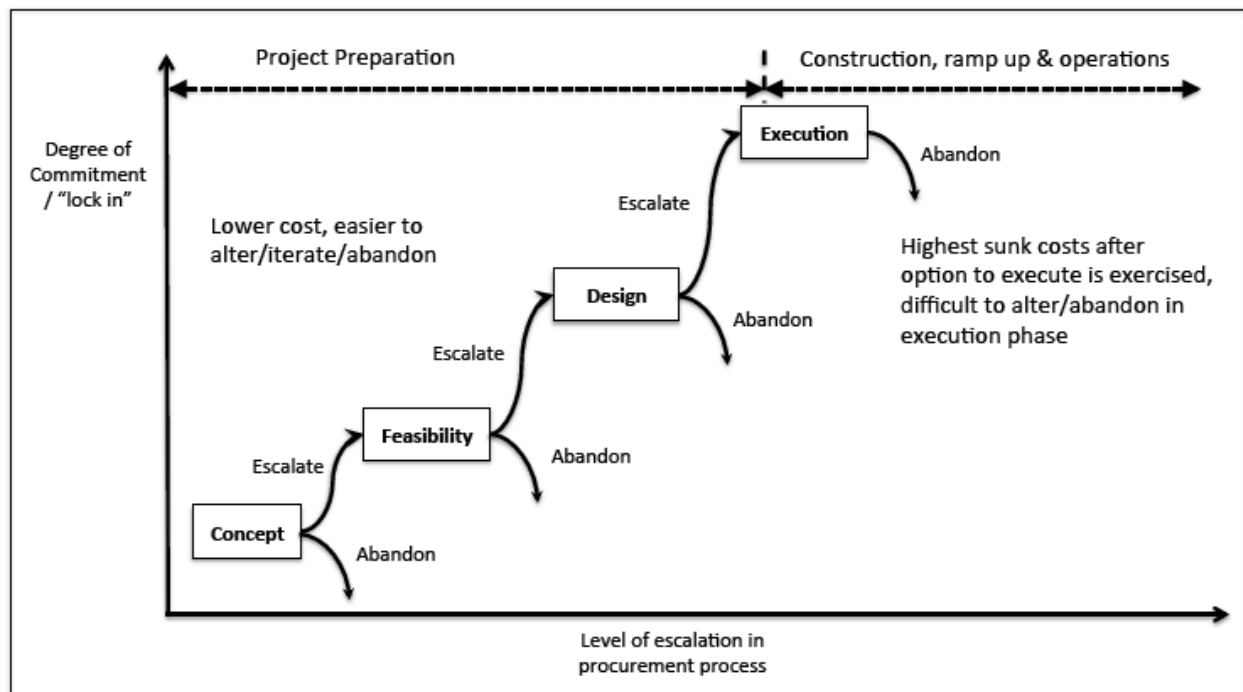


Figure 1. Consequences of abandonment in relation to degree of lock-in (adapted from Miller & Lessard, 2001a)

The phases of Concept, Feasibility and Design, collectively termed as Project Preparation, precede Execution (comprised of construction, ramp-up and operations). As project procurement proceeds from Concept to Feasibility, and then to Design, the degree of lock-in increases. In other words, designers or project managers continue to fix various degrees of freedom. The project incurs costs in going from one phase to the next such as the cost of feasibility studies, environmental impact assessments, initial permitting and so on. Moreover, as specificity increases, the relative magnitude of these costs increases exponentially due to the increasing level of detail and precision in subsequent phases of project preparation. The costs of project preparation pale in comparison to the capital expended during actual construction, “when the concrete is poured,” which usually represents the most expensive phase of the project in terms of sunk capital. At each phase, the project can be de-escalated or abandoned, but abandonment costs increase along with the degree of lock-in. The relative cost of abandonment is highest during Execution.

The traditional and flexible approaches to procurement see the same process differently.

Table 1 summarily compares their main attributes. The traditional approach proceeds linearly through the procurement process without fully recognizing the iterative nature of front-end design, or the options for de-escalation and abandonment. Decision-makers fix the output or service specifications for the project, and move onto increasingly detailed design, contracting, engineering, and construction work. Feasibility studies cover a few design concepts at best with the implicit assumption that only one concept will be chosen for subsequent stages. This process requires key stakeholders either to agree on or assume the “fixed” specifications of the project, so as to converge on a feasible design (de Weck et al, 2004). While the traditional approach permits some iterative “re”-design, the major actors operate in a mind frame that does not allow systemic changes in later stages. The traditional approach does not value, and even discourages the idea that major strategic changes later in the process may be beneficial to the system. This approach also assumes that cost-benefit analyses will illuminate the cost-value trade-off presented

by various project solutions. In reality, costs are uncertain, and future benefits beyond the construction of the project are generally even more uncertain. This makes finding the optimal tradeoff conditions difficult.

Table 1. Comparing “Traditional” with “Flexible” procurement

“Traditional” Procurement	“Flexible” Procurement
<ul style="list-style-type: none"> • Identify needs today, fix output/service specifications based on forecasts • Define, design, and move to execute <i>today!</i> • Emphasizes finding optimal cost-value tradeoff <i>ex ante</i>, before major uncertainties are resolved • Requires stakeholder pre-commitment to full sequence of decisions, before major uncertainties are resolved • Offers little to no flexibility to re-direct performance trajectory 	<ul style="list-style-type: none"> • Identify needs, but recognize that they may change; the forecast is always wrong • Phased approach: execute some today, defer some important decisions until <i>later!</i> • Emphasizes improving life-time performance and value by making decisions contingent on new information about uncertain factors • Requires stakeholder commitment to re-evaluating decision options, and monitoring how uncertainties are resolved • Offers opportunities to re-direct the course of the system

In contrast, the flexible approach recognizes the trade-off between degree of lock-in and the consequences of escalation in front-end procurement. It assumes that forecasts used to fix specifications are “always wrong” in that they do not correctly anticipate the specific needs to be met. Decreasing the reliance on forecasts and analyzing the wide range of possible outcomes over time can prepare decision makers for opportunities as well as contingencies. This approach also recognizes that whereas some decisions can be executed today or in the near future, because the circumstances are well defined, other decisions can only be finalized later on, due to the time lag for information gathering and preparatory work.

In the flexible approach, decision-makers improve their estimates of future conditions through a process of exploration, information gathering and monitoring. They secure the ability to escalate to suitable detailed design by first undertaking feasibility studies on design variants at relatively small costs. They keep stakes low initially, and gradually increase commitments as they develop more confidence in a particular course of action. Decision-makers can also abandon the project at relatively low cost during

project preparation if feasibility studies uncover unexpected challenges. A fundamental motivation of remaining flexible is that adapting to changing circumstances enhances value. Flexible procurement is therefore particularly suitable in conditions of deep uncertainty and risk.

We recommend the flexible approach, but recognize obstacles to its adoption. The approach calls for a governance process in which decision-makers monitor relevant trends, periodically re-evaluate decision options and reconvene stakeholders accordingly. Managers actively incur the transaction costs of remaining flexible to avoid the costs of wasted effort and delays that may arise during project redefinition and restructuring. A flexible approach is useful when the performance trajectory of the system may have to be redirected, as for some major infrastructure undertakings in a development context.

(c) Need for flexibility in procurement

To the best of our knowledge, few analyses focus on the relationship between procurement practices and infrastructure project outcomes, and almost none focus specifically on flexibility (Guasch, 2004; Gómez-Ibáñez, 2003; Merrow, McDonnell, & Argüden, 1988; Merrow, 2011; Miller and Lessard, 2001a). Literature on the auctions phase of procurement is an exception (Estache and Iimi, 2010). Most studies focused on flexibility, or even project outcomes more generally, typically examine individual projects and cases (Gil, Beckman, & Tommelein, 2008; Gil, 2009; Gil & Tether, 2011). This is not surprising given the confidential nature of project delivery mechanisms and the lack of systematically collected data, or access to detailed information on projects. Authors of some large-N studies do broadly identify the need to understand the effect of uncertainty on expected project performance early in the procurement process (Flyvbjerg et al., 2005).

A number of reports generally emphasize the value of flexibility in front-end project design. Guasch (2004) identified determinants of contract renegotiations in an extensive analysis of about 1000 concession contracts. He states that optimistic demand forecasts for infrastructure services, especially in the transportation sector, commonly influenced the front-end concession design process. Flyvbjerg et al (2003) make the same point using a separate dataset. Miller and Lessard (2001a) and later Merrow

(2011) discuss how stakeholders strategically shape large infrastructure projects in the front-end design phase – the most flexible phase of decision-making – to accommodate various types of risks. In terms of engineering design, de Neufville and Scholtes (2011) describe mechanisms for incorporating flexibility in systems design more generally, i.e. beyond the infrastructure domain.

(d) Analysis of World Bank experience

Our analysis looks at the typical procurement process for development projects and associated data to identify the outcomes of front-end phases. A main observation is that institutional incentives limit managerial flexibility in development projects. To illustrate, consider the World Bank's procedures for awarding a 'specific investment loan' (SIL), its primary instrument for infrastructure lending.

To be approved by the World Bank's management and its board, the details of an SIL must be specified in a 'project appraisal document' (PAD). In particular, this must include a procurement plan and an environmental and social ('safeguards') assessment. These two elements – procurement and safeguards – impose limits on project flexibility. Procurement plans must identify specific actions and their approximate funding needs, while the safeguards assessment needs a project concept detailed and firm enough to be assessed. The loan, once approved, must be for a specific sum of money.

If a larger amount is needed later, project managers must request additional financing. This is cumbersome, except under 'emergency procedures'. Such requests can be avoided by over-budgeting, or using reference-class forecasting – benchmarking with a large number of similar projects (Hodge, 2009). While this approach allows for a budget ceiling, it may also reduce managerial incentives to keep budgets and costs low.

World Bank systems track the rate of disbursement of any given loan, in terms of the percent of funds disbursed to date. If this is below the approved disbursement profile then the loan is flagged as problematic and requiring managerial attention. A track record of low disbursement of loans is perceived to be highly negative. While there are good reasons for this – in many projects, a low disbursement rate

is not related to cost savings or reallocation, but to bad design or implementation – it does set up an implicit institutional barrier to flexible design. Many project managers would recoil at the idea of a project explicitly designed with a high chance of not needing all its funds. As a result, a project is only likely to be downsized if other activities can be found to use the funds thereby released. Cancelling a project, or significantly reducing its size, can take a year or more.

Feasibility studies and environmental assessments, as a rule of thumb, cost 1-2% of the overall investment, and take up several years of project time. Pursuing feasibility studies for different project concepts and designs in parallel significantly reduces the time requirement compared to beginning new feasibility studies after initial concepts are discarded, while also uncovering much more information about the viability of a project at very little cost. However, requesting multiple studies up front informally risks the accusation of “not knowing what you want”, and formally will run into budget constraints. In a cost-constrained aid environment, multiple studies can seem a luxury, especially if funded out of administrative rather than investment budgets. Most projects are therefore based on a very small number of design concepts and feasibility studies.

A standard World Bank project is quite inflexible by design. If circumstances change, the project concept itself will need to be altered, triggering ‘restructuring’ at one of two levels. A level one restructuring, requiring re-approval by the Bank’s Board, is triggered if the development objective changes, or if the project moves from a lower to a higher category of environmental risk. A level two catches all other changes, and requires approval only from the Country Director, and maybe the Regional Vice-President.

Reliable evidence on the number of and reasons for projects undergoing level one or level two restructuring is unavailable. To overcome this we drew on three distinct World Bank documentation sources: the SAP system (the Bank’s ‘business warehouse’), document archive, and the ‘Implementation and Status Reports’ (ISRs) repository. In principle, every restructured project must (i) be flagged in SAP along with the reason for restructuring, (ii) file a ‘restructuring paper’ with the archive, and (iii) record the restructuring in its ISR at the end of the fiscal year. However, monitoring differs in strictness for each of

these steps: filing a restructuring paper is a legal requirement and most strict, whereas making a note of restructuring in the ISR is a management requirement after the fact.

SAP lists approximately 11,500 restructured projects as of August 2012. Only 783 projects include a date of restructuring, of which 87% were restructured in 2000 or later. Knowing that most digital records were only captured after 2000, we assume between 75 – 90% of restructurings occurred after 2000, on average between 700 and 850 per year. Data from the Bank's document archive covers a narrower period. After substantial cleaning and sorting for duplication and incomplete data, we identified 570 projects that filed a restructuring paper in the 14-month period between June 2011 and August 2012. We thus estimate that in a given year, 500-850 projects will be restructured. Given 1,699 active projects in August 2012, around one third to one half of all World Bank projects may be restructured every year. The fraction for infrastructure projects is greater on average. About 45% of projects in the sub-category that includes infrastructure (354 of 780 active projects) were restructured. The ISR data appears to significantly underestimate the frequency of restructuring compared to the other two sources – only 11% of the 10,853 projects in the ISR database made a note of restructuring – possibly because of less stringent monitoring and subsequent underreporting by managers.

Table 2. Restructuring papers filed from June 29, 2011 – August 23, 2012, by World Bank network

Network	Sectors	Projects filing a restructuring paper		
		Same funding envelope	Seeking additional finance	Total
Sustainable Development	Transport, power, water, agriculture, urban, social, environment	302	52	354
Financial and Private Sector	Capital markets, financial stability, financial inclusion, investment climate, innovation, competitive industries	29	4	33
Human Development	Education, health, social protection and labour	130	20	150
Poverty Reduction and Economic Management	Economic policy and debt, public sector governance, poverty reduction and debt, international trade, gender and development	30	3	33
Total number		491	79	570
As a percentage of all projects active in this period		29%	5%	34%

We suspect the bulk of restructured papers were filed for simple project schedule extensions, due to delays in implementation. While the mean and median project schedule lengths are 4.1 and 4.9 years respectively at the time of approval, the median completion length of a project is 6 years. Project schedule appears to be systematically underestimated. The ISR data may support the conjecture that most restructuring papers were filed for schedule extensions, since ISRs are compiled at the end of the fiscal year, and not at the time of restructuring. A restructuring event perceived as insignificant in hindsight may slip through the ISR reporting process. Anecdotal evidence suggests that routine extensions to project closing dates may therefore go unreported.

Restructuring could also have occurred for two other reasons: requests for reductions in funding, or reallocation of funds among changed project activities. The first is unlikely to be a significant driver because there are many barriers to reducing funding after project approval. Both clients and Bank teams are loath to give up funds. For example, a particularly problematic \$1 billion loan that had disbursed no more than 2% of available funds well into the project life required years of negotiations to reduce and redirect the funds. Reallocating funds among project activities while holding the total budget constant may also have driven many restructurings, however the burden of proof for internal sanction is higher. Furthermore, many requests for schedule extensions may dovetail with reallocation requests, making it hard to separate the contribution of the two.

In summary, extending project deadlines and altering allocations among project activities is a norm among development projects, not an exception. At the same time, adjusting the overall funding envelope of a project is difficult. No more than 5% seek extra funds, and few to none seek to release funds. Altering a project in such a way as to change its environmental impact is also extremely rare - if restructurings requiring board approval are a rough proxy for these, they consist of only 3% of projects. Given the incentives to stick to the prescribed procurement process, project managers cannot effectively conduct a sophisticated information search on different design concepts or evaluate them in advance of budgeting and approval.

Flexibility can be increased by exploring many project concepts using small budgets for feasibility and preliminary design studies, and by deferring requests for large sums until more clarity about the most beneficial project concept is obtained. This will likely reduce the over-commitment of funds and also potentially improve the allocation of funds among project activities. Flexibility becomes increasingly important when infrastructure development occurs in highly uncertain environments such as Resource Corridor Programs.

(e) Resource Corridor Programs: an application area

Economic and resource corridor programs contain pervasive uncertainties. The viability of key projects is linked to volatile regional and global markets, the unpredictable performance of industries and growth of cities in the corridors. Resource corridors have historical precedence, largely implicit – for example, the coal belt in England or the Ruhr valley in Germany. Since private investments in mining and oil & gas need power, transportation and water to sustain operations, the public sector can often leverage the demonstrated needs and revenues from private projects to pursue ancillary investments in the public infrastructure sectors. Recently, resource corridors have thus been explicitly planned and developed in Chile, Mozambique, Zambia and elsewhere. The Delhi-Mumbai Industrial Corridor (DMIC), one of the Government of India's flagship investment programs is another example. It envisions development of some major cities and a large-scale port at an estimated investment of US \$100 billion.

The first resource corridor program to be officially named as such was the Maputo Development Corridor (MDC), between South Africa and Mozambique, founded in 1995. As of 2013, it has helped facilitate investment of over US \$5 billion in regional infrastructure development, industrial development and natural resources exploitation and downstream processing. The Corridor includes one of the world's largest aluminum smelters, an iron and steel complex, a 600-hectare industrial free zone development, and numerous smaller investments in tourism, retail and manufacturing. As a case of turning a private into a public good, a planned mining port on the bay of Fort Dauphin, Madagascar, was made multi-use and allowed to diversify into tourism and transport for regional food markets.

Given the interdependencies and uncertainty, the questions of which projects to build (project selection), who is responsible (public or private role), when to build and how much (timing and phasing), and in what order (sequencing) are not straightforward. Different approaches to assessment and procurement emphasize different objectives and mechanisms. Section 3 discusses some general principles for making procurement more flexible, and Section 4 demonstrates their application in a real world case study in the context of a Resource Corridor Program.

3. PRINCIPLES FOR MAKING INFRASTRUCTURE PROCUREMENT FLEXIBLE

We suggest three principles for increasing the flexibility of procurement for large infrastructure projects: (1) conducting uncertainty-based analyses, (2) broadening the system boundary, and (3) phasing designs. These work together to provide a more insightful comparison of available courses of action. After describing the principles, we demonstrate how to apply them in a practical analytical analysis in the subsequent section.

1. Uncertainty Analysis: *Acknowledge and treat uncertainty directly.*

Sidestepping uncertainty analysis often obscures the real picture and misleads the analyst and decision-makers, making them unduly optimistic about the potential outcomes of projects (Kahneman et al, 2011). The objective should be realism. Uncertainty analysis provides a better understanding of the downside risks as well as the upside opportunities. In development procurement, implementing this principle implies avoiding deterministic economic analyses in feasibility studies, structuring safeguards assessments around multiple project concepts, and creating a sentiment within procurement that not knowing project needs upfront is not always negative.

2. System Boundary: *Broaden the system boundary to understand how project(s) affect the system.*

Procurement often treats infrastructure projects as stand-alone independent ventures; this makes them easier to analyze, design and implement. Some projects may actually worsen the performance of the system as a whole, even if worthy on their own merits. The goal of improving system performance or value reduces the tendency to focus myopically or “locally” on the project(s). A systems approach also

opens up alternative of sets or programs of opportunities. In procurement, this means evaluating discrete infrastructure projects as part of a larger program, along with other possible project opportunities.

3. Phased designs: *Employ a phased “option”-based decision-making process.*

While there is pressure to lock into specific project concepts early in the procurement process, we suggest a phased course of action that specifies broad system performance goals upfront instead of specific design solutions. Specifying broad goals and direction allows managers to undertake project preparation, feasibility and early design studies at relatively lower costs than if they committed to a final design solution before important uncertainties have been resolved. Rather than a “now or never” decision-making paradigm, we recommend a “prepare, monitor, and re-evaluate” perspective which allows for delaying the escalation of commitment. In development, this implies budgeting for and undertaking multiple feasibility studies and safeguards assessments and then deciding which specific investment to undertake at a later stage during execution.

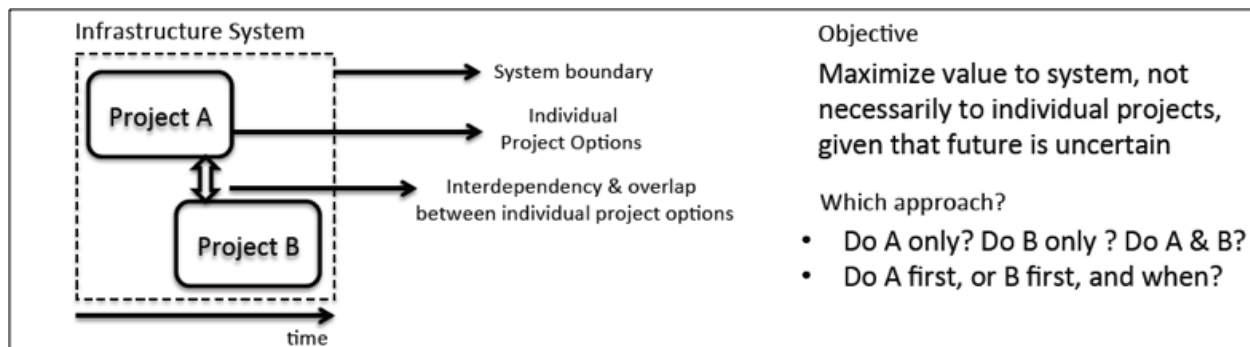


Figure 2. Principle of ‘Broadening the system boundary’

The initial example of electricity projects - Project A: Transmission Line and Project B: Power Plant – also clarifies the three principles for flexible procurement. Figure 2 is a stylized representation of the second principle, broadening the system boundary. Projects A and B are arranged chronologically from left to right along a time axis. The time-based overlap denotes that project managers may have to begin execution on the power plant before the transmission line is fully completed, as is often the case. Furthermore, the bi-directional arrow indicates that the projects are interdependent, i.e. the power plant is useful only when its power can be transmitted, and the line is useful because there is power to transmit. The dashed box around the two projects denotes our system of interest.

The main objective for design concept evaluation in this example is to understand how to enhance economic value to the system under uncertainty, and not just the value of individual projects A or B. The ‘Traditional’ versus ‘Flexible’ procurement paradigms can lead to different design choices. In the traditional paradigm, projects are treated as stand alone projects. Decision-makers would typically use deterministic power demand forecasts to select the apparently more economically valuable design variant for each of the Power Plant and the Transmission Line. However, the appropriate metric in this example is the system value in operation – the combined value of the different design variants - because executing either the plant or the transmission line exclusively is not useful – both must be executed to supply power to customers.

Acknowledging uncertainty in power demand affecting the system, the first principle, leads decision-makers to explore different combinations of the design variants. The combination of ‘Large power plant, low capacity transmission’ can be ruled out immediately as an infeasible design strategy because of the line’s capacity limitation. Of the other three combinations, ‘Small power plant, low voltage transmission’ is more valuable in low demand scenarios, whereas ‘Large power plant, high voltage transmission’ is more valuable in high demand scenarios. Not knowing in advance which scenarios will materialize, decision-makers could conduct feasibility studies for all three combinations at a fraction of the cost of definitively pursuing any of the design strategies.

Employing a phased design with an option-based decision process, the third principle, avoids costly premature lock-in to any particular design concept. In the example, decision-makers should defer the commitment to definitively pursue any design variant until the preliminary studies have uncovered the advantages and challenges of each variant. Valuable time is conserved since time-intensive studies have been completed in parallel, while allowing decision-makers to simultaneously monitor trends in demand growth. Construction on a high capacity transmission line can then begin with an intentional delay in building the small power plant, with the option to increase generation capacity if demand grows rapidly. Crafting such a design strategy allows for flexibility in meeting realized needs, while avoiding capacity underutilization and stranded costs.

4. STUDY DESCRIPTION: URBAN WATER SYSTEM DEVELOPMENT

This section illustrates how the three principles can be implemented in practice. It uses an analytical study inspired by a real-world development of an urban water system. The case study demonstrates how the issues of information search and concept evaluation play an important role in the procurement of an infrastructure system. It first describes the challenges decision-makers face in designing the system, and then provides an overview of the analytical approach for concept evaluation. The analysis closely follows the three principles discussed above and ends with a recommendation of how to make the procurement process more flexible in this case.

(a) System design problem

The Kabul government has been exploring ways to improve the supply of potable and non-potable water to its residents and businesses. As of 2013, most water supplies were sourced from local aquifers in the city's footprint. The city draws approximately 30 million cubic meters (cu. m.) of water per year, or about 80-120,000 cu. m. per day. Planners and regulators are concerned for a few reasons.

First, the city expects regional population and economic growth to increase rapidly, but with a high degree of uncertainty. This growth will greatly stress the current system's ability to meet the demand for water. The medium depth aquifers are being depleted (the water table fell 11m from 1990 to 2008). Any increase in the water intensity of domestic and economic activities will exacerbate expected demand shortfalls. Second, the local aquifer system – the main source of current water supply - presents increasing health risks due to pollution from untreated domestic wastewater and other effluents discharged in the region. The city at present has virtually no wastewater management or treatment systems. Third, the water system is old and inefficient: an estimated 35 to 40 % of supplied water is lost physically due to leaks and evaporation. Finally, a new copper mining venture located only 35 km away from the heart of the urban region would draw water from the same aquifer, thereby significantly increasing overall water demand. Using aquifer water for copper mining presents a public policy dilemma in terms of how water should be allocated among different end uses. The copper mining venture has brought water system issues to the

forefront; whereas the local government may otherwise have developed the water system at a slower pace, the city now faces a serious near term risk of severe water quality and shortages.

The mining venture is flagship project in a Resource Corridor Program. It is regionally and nationally important in terms of its potential economic and reputational returns. The mine will exploit a world-class copper deposit, among the largest undeveloped worldwide. Its copper concentration of 2.3% is high by global standards (for comparison, Oyu Tolgoi in Mongolia, another large mining venture has 0.78-1.33% copper content). Some social and environmental concerns have delayed the construction of the mine, but it could start production within three or four years. At steady-state production, the mine could generate US \$400-450m in government revenue (at the 2013 global price in the range of \$7,500-8,000 per ton). If successful, the mine could provide a framework for advancing other projects in the resource corridor.

Recent preliminary and feasibility studies of the Resource Corridor, including the mining venture, have revealed that the project is intimately connected with the urban water system. Both the urban water system and the copper mine depend on water from local aquifers. The water system must therefore be developed so that both the city and the mine have sufficient water.

Copper mining is water-intensive. Copper mines in dry or desert environments (such as Afghanistan and in Chile), typically consume between 0.4 to 2.1 cu. m. of water per ton of ore. Higher figures correspond to operations where water is not recovered; lower ones to those that use high-density thickeners to recover water from the ore extraction process. Applying these figures to our mining venture results in a daily net consumption of anywhere between 25,000 and 80,000 cu. m.

Local decision-makers and stakeholders are alarmed because the mine would draw somewhere between one and two thirds the amount of water that the urban region as a whole uses, and both sources of demand are uncertain. If the city grows as expected, and if water use rises to that of other low income countries (40 litres per capita per day, LCD), demand will rise to almost 90 million cu. m. per year by 2025. But this could vary by 30-40%, because population growth is highly uncertain and per capita water

use will depend on a range of other factors, from income growth to the pace of construction of the water distribution network to climatic conditions.

One way to approach the development of the water system is to focus narrowly on the mine. Within this small system boundary, the mine can be required to adopt a less water-intensive design at somewhat higher cost, using industry best practice. However, a broader system boundary that includes aspects of the urban water system infrastructure and supply sources may reveal other approaches to meeting water needs. The mine's water needs should then be considered within that system as a whole, including the system's other supply options, and their attendant costs and benefits.

Possible new supply sources include the option to construct a dam on a nearby river. The development of the dam would require approximately US \$300 million and at least five to ten years for construction. Other aquifers in the region could also be exploited at much lower cost in the near term. However, little data exists on their groundwater quality and the feasibility of transporting their water to the city distribution system. Exploring these other supply sources could dramatically influence the choice of system development strategies available to decision-makers. Given the central importance of pursuing the public policy goals of improving water supply and supporting the mining venture, decision-makers can look for ways to construct a win-win solution that would address the needs of the water system as a whole even with a high degree of uncertainty in water demand and supply source options.

(b) Analytical approach and technical method

The analytical approach is aligned with the three principles discussed earlier. The first step is to evaluate water demand as the fundamental uncertainty driving system design decisions. The second step is to formulate the design variants or design strategies that involve one or more interdependent water system projects. The third and final step is to evaluate strategies and identify those that enhance system value in terms of some suitable metric such as Net Present Value (NPV).

Water demand was modeled as a stochastic process and simulated directly to create a demand state space, the set of possible demand outcomes in each time interval across the horizon of the study. By developing a Monte Carlo simulation of a random walk process, a very large number of possible “paths” of demand evolution (specifically 10,000) were produced to create the demand state space. The time horizon of this simulation is also large, about 35 years, allowing for significant variance in the state space over this time horizon. Annual water availability from aquifers was modeled using lognormal probability distributions. The main rationale is to use a probability distribution that is bounded at zero on the lower end and is positively skewed, i.e. with an asymmetrically low probability of extreme high values.

Preliminary studies for the development of the urban water system looked at a number of supply options involving distribution system expansion, ground water development, storage reservoirs, and small-scale hydro development. Each possibility was evaluated as a stand-alone project, and the studies reported the attractiveness of projects in terms of Net Present Value (NPV), Internal Rate of Return (IRR), and Economic Rate of Return (ERR). However, these studies did not address the interdependencies between these project possibilities, and their effect on overall system value. Our analysis explicitly considers the project opportunities as part of the broader urban water system, and evaluates various ‘system design strategies’ to study their effect on overall system value.

Table 3. Description of System Design Strategies and associated Key Interdependencies

System Design Strategy	Key Interdependencies
1. ‘Do nothing’	A benchmark or reference case with no distribution system enhancements and unutilized new supply options
2. ‘Enhance distribution system’	Opportunity to meet demand through centralized distribution, reducing reliance on increasingly polluted and depleting ground water
3. ‘Develop aquifer’	Explore and sink wells in hitherto untapped aquifers; distribution system enhancements as a pre-requisite for conveying new supply to urban demand center
4. ‘Build dam’	Creates storage capacity, sizing of the dam depends on demand, and groundwater development; sequencing of groundwater development and dam may affect system value.
5. ‘Phase aquifer and dam’	A flexible strategy where aquifer is first developed; then demand trends are monitored for five years to inform decision to build dam

There are four 'inflexible' or unphased strategies, and one flexible phased strategy, listed in

Table 3 along with key interdependencies between projects in the respective strategies. These alternatives are:

- 'Do nothing' is the benchmark to which the others can be compared. It provides a possible 'world' to which comparisons can be made, since the state space used across all strategies is identical. It represents the case in which decision-makers do not execute any project opportunities.
- 'Enhance distribution system' is one of the basic project opportunities available. With an improved distribution system, residents of the urban area will reduce their reliance on increasingly polluted groundwater in the local aquifer. An enhanced distribution system also increases efficiency in terms of reduced physical water losses. However, large increases in future demand can only be met through new supply sources.
- 'Develop aquifer' is a strategy for increasing water supply from natural sources. It requires both conveyance infrastructure and distribution enhancements for supplying water from the aquifers to the urban water system.
- 'Build dam' involves building a surface storage reservoir to provide capacity that can be replenished through run-off, or groundwater. There are two feasible sizes, small and large. The dam can be combined with aquifer development and distribution system enhancement. Building the dam involves decisions concerning timing, sequencing with other projects, as well as size.
- 'Phase aquifer and dam' is an inherently flexible strategy. It assumes that decision-makers will first develop aquifers and then monitor demand trends for another five years to decide whether to build the dam as a follow-on project.

Cost and benefit streams are discounted to arrive at a Net Present Value for each design strategy. While NPV has inherent limitations as a metric, discounted cash flow techniques on which it is based are by far the most appropriate techniques for adjusting for the time value of cash flows, and for the risk represented by the variance in cash flows. Sensitivity analyses with the discount rate demonstrate the

effect of varying perceptions of risk on the cash flows, while avoiding the problem of selecting a single discount rate.

The final step of analysis compares the system design strategies in terms of Net Present Value, arranged in the form of a decision tree, as Figure 3 shows. Each design strategy is first evaluated without the mine as part of the water system, and then with the mine. This approach shows whether including the mine's water demand makes some design strategies more attractive than others, given demand uncertainty.

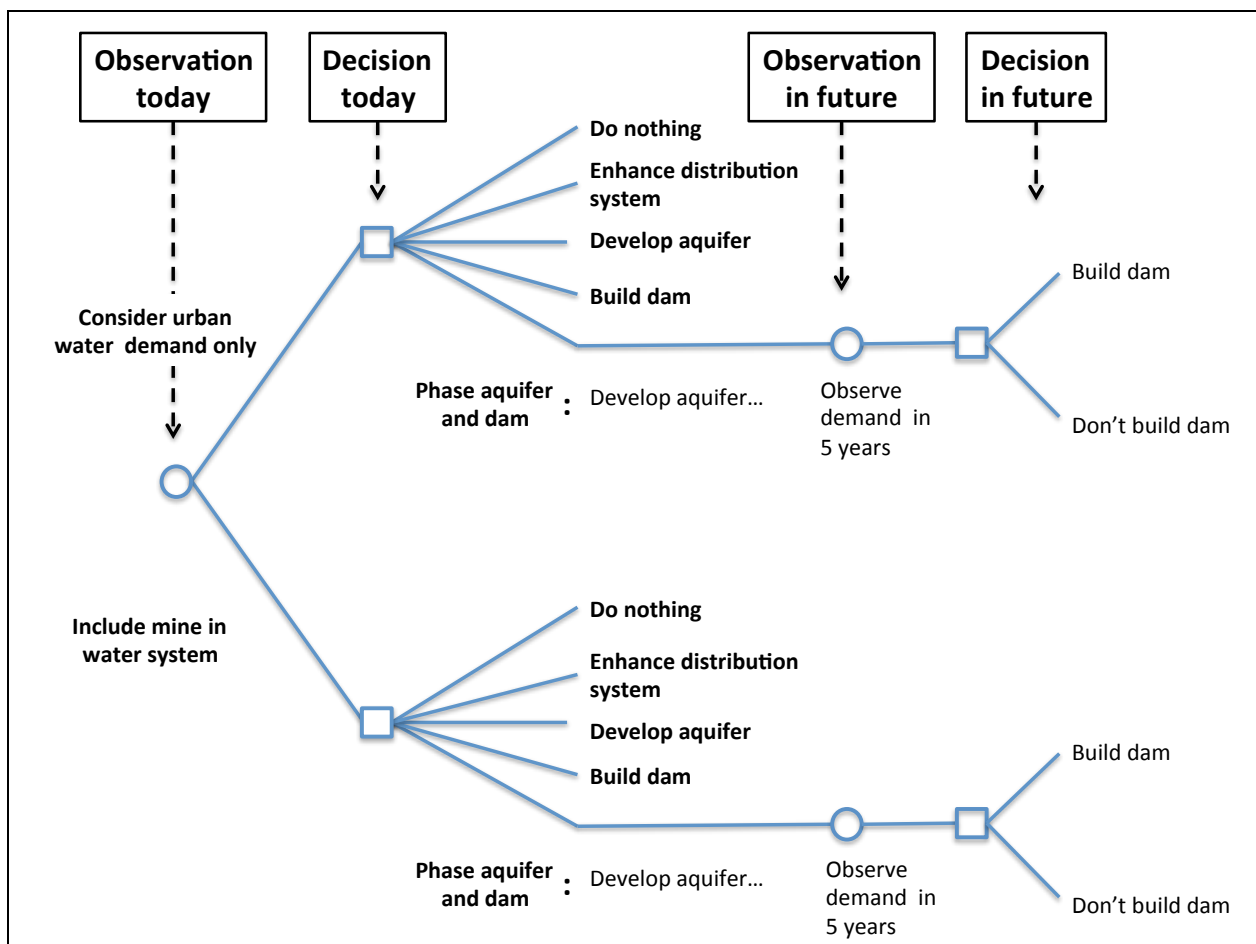


Figure 3. Decision tree of strategies to be evaluated

(c) Main results and insights

The first step of the analysis - simulating uncertainty in water demand - creates a stochastic state space for the evaluation of system design strategies. While the Monte Carlo simulation uses 10,000 iterations, Figure 4 demonstrates the result for just three 'sample paths'. The smooth line in the center of the distribution is the forecasted median growth path in the preliminary design studies of the water system, on which most of the investment proposals are based. In comparison with this median projection, the three sample paths show that demand growth is volatile – not only can the final demand state (at the end of the time horizon in 2035) differ significantly from the assumed forecast, but the growth rate can also vary from year to year.

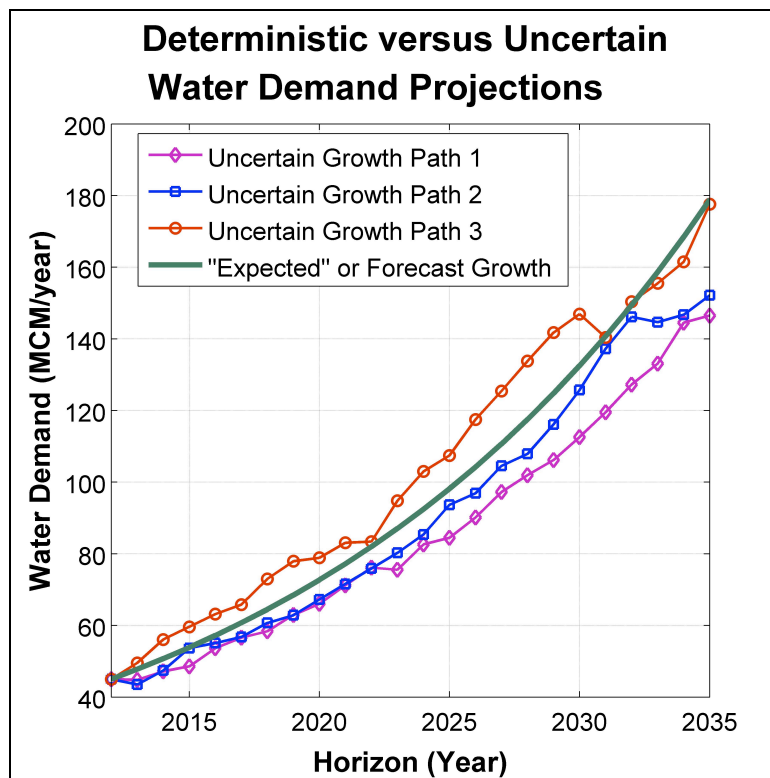


Figure 4. Deterministic versus uncertain demand projections

With the demand state-space available, the design strategies could be evaluated in terms of Net Present Value to the system. A discount rate of 7.5 % / year was used at the outset, and varied later in a sensitivity analysis. The analysis was first conducted without the mine as part of the water system.

Figure 5 compares the value distribution of the four inflexible system design strategies. 'Do nothing' imposes a huge cost on the urban water system, a loss of approximately US \$ 200 million as a central estimate over the study horizon (2010- 2035). While this cost could be as low as US \$ 150 million, it could be as high as US \$ 250 million. Doing nothing is costly because of the latent social value of unmet water demand. This value is calculated using consumers' willingness-to-pay for potable water (2% of total demand), a standard approach for water pricing in the absence of water markets, and tariffs as a proxy for the price of non-potable demand (the remaining 98%)(National Research Council, 1997). With 'Do nothing' as a reference situation, other system strategies can now be compared to it.

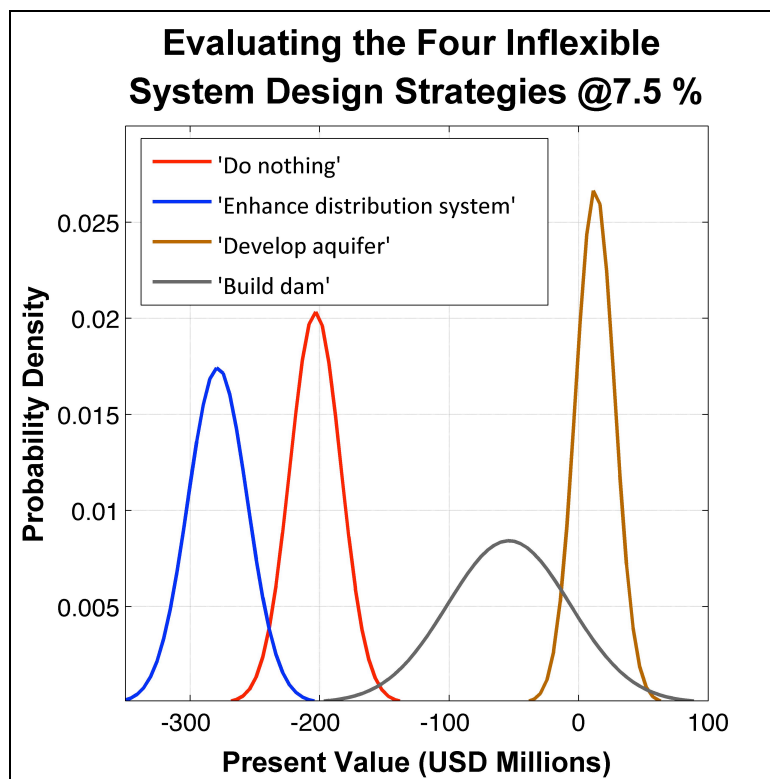


Figure 5. Evaluation of inflexible system design strategies using a discount rate of 7.5% / year

'Enhance distribution system' is to the left of 'Do nothing', a loss centered near US \$ 300 million. Unsurprisingly, the enhanced distribution system imposes significant costs on the system with very little gains through efficiency improvements. Increasing demand is still largely unmet since there are no new supply sources.

'Develop aquifer' contributes positively to system value since demand is met through new supply. Note that enhancing the distribution system is implicit in this strategy because of the need for conveyance and distribution to the urban demand center. While 'Build dam' is also a value-positive strategy, it is less valuable than 'Develop aquifer' because of the high capital costs of dam development, and the long build time taken to complete it (assumed to be 5 years). The dam is a riskier design option as seen from the wider probability distribution in Figure 5. Thus, 'Develop aquifer' is the most valuable of the four inflexible strategies. It is attractive because its capital costs are much lower than dam construction, the alternative, and aquifers can be developed more quickly in a few years.

In the 'Phase aquifer and dam' flexible strategy decision-makers develop the aquifer first and then wait five years to see how demand evolves. The dam is added as a follow-on project only in high-demand scenarios. Compared to the best inflexible alternative, the intentional phasing of the dam with the aquifer increases system value on average even with its requisite capital costs (Figure 6). It also reduces the dam's economic risk in comparison with the inflexible 'Build dam' strategy. This observation provides direct support for building in flexibility into more traditional design strategies by executing multiple project options in phases.

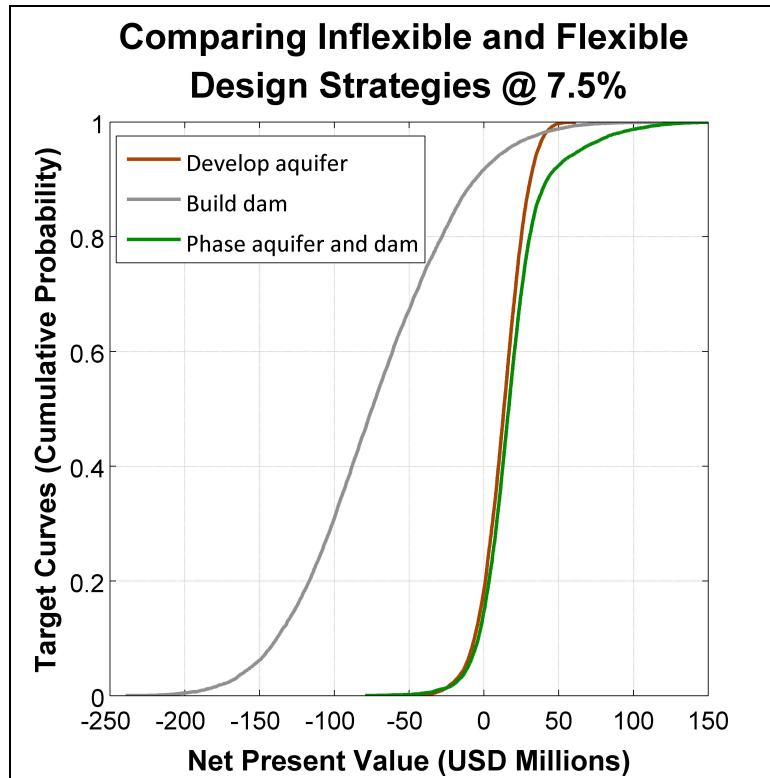


Figure 6. Comparing a flexible strategy with inflexible strategies using target curves

A sensitivity analysis of the main results using different discount rates from 7.5 % to 12 % per year shows that the flexible strategy 'Phase aquifer and dam' is always more valuable than the inflexible strategy 'Build dam'. However, at the higher discount rates, 'Develop aquifer' is most valuable because the high capital costs of the dam and a significant delay in its benefits reduce their contribution to system value.

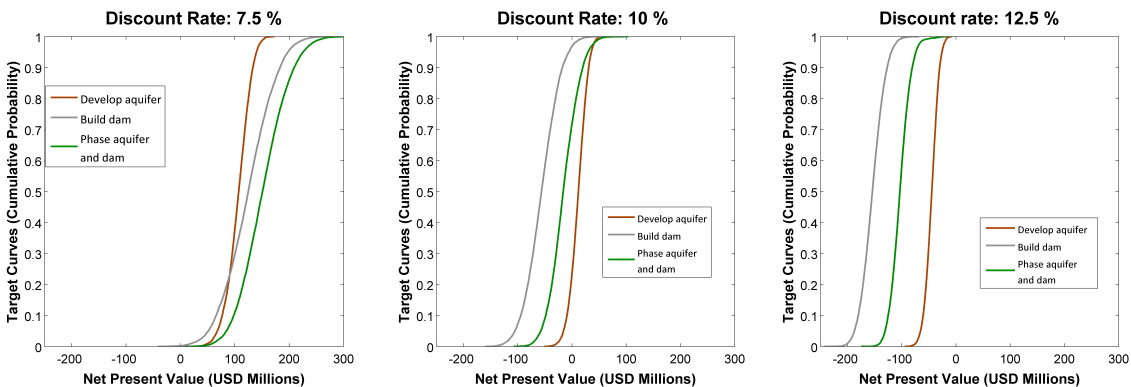


Figure 7. Example of discount rate sensitivity analysis at 7.5, 10% and 12.5 %/ year

The analysis was repeated with the mine as part of the urban water system. The implication of including the mine is that it imposes a relatively steady source of water demand for copper processing, and will also return revenues to the system for being a high-valued customer. The main results are compared in Figure 8. Including water demand for the mine moves the system to the high demand scenarios of the state space. The first implication is that the main new supply strategies are all value-positive. Further, the dam-related strategies become more valuable than ‘Develop aquifer’. The flexible strategy ‘Phase aquifer and dam’ is the most valuable and dominant solution; its cumulative probability distribution is rightmost.

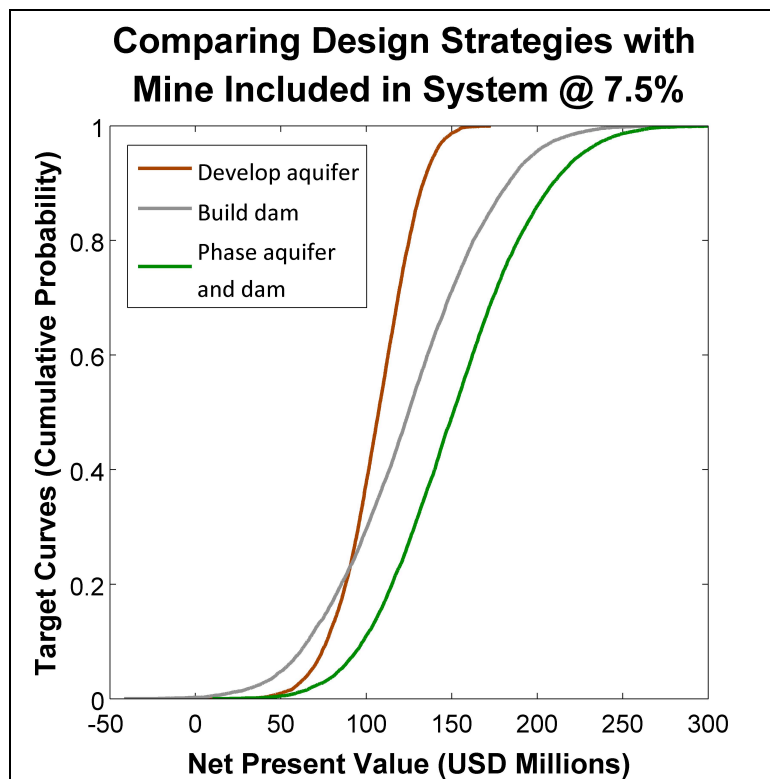


Figure 8. Effect of including the mine in the system

The main results of the case study analysis are listed in Table 4 to show how system value changes as a function of the chosen strategy and of whether the mine is included in the urban water system. The table

shows percentile values for system NPV for two inflexible system strategies and the one flexible strategy: 'Develop aquifer', 'Build dam', and 'Phase aquifer and dam'. For each strategy, the percentile values indicate the likelihood that system NPV is at least as high as the listed value. For example, the median (50th percentile) system NPV for 'Develop aquifer' is USD 13 million when the mine is not included in the urban water system, and USD 107 million otherwise. Reading down the columns for each percentile level identifies the dominant strategy. 'Phase aquifer and dam' dominates because it has the potential to result in the highest system NPV for each percentile level, both without and with the mine included in the urban system. The phased flexible strategy thus not only improves system value on average (USD 151 million instead of 16 million), but can also capture much more of the upside potential for high demand scenarios with the mine is in operation (USD 226 million instead of 65 million). This result directly informs the procurement process for the urban water system.

Table 4. Summary of results for Urban Water System analysis with and without the mine

Urban Water Demand Only					
System Strategy	CapEx (USD millions)	System Net Present Value (USD millions)			Time to Deliver (years)
		5th percentile	Median	95th percentile	
Develop aquifer	725	(12)	13	36	2
Build dam	885	(155)	(75)	15	5
Phase aquifer and dam	950	(10)	16	65	10

Urban Water Demand + Mine Included in System					
System Strategy	CapEx (USD millions)	System Net Present Value (USD millions)			Time to Deliver (years)
		5th percentile	Median	95th percentile	
Develop aquifer	725	68	107	140	2
Build dam	885	50	125	196	5
Phase aquifer and dam	950	84	151	226	10

Note: figures in parantheses indicate losses, i.e. negative NPV

Figure 9 summarizes the recommended flexible procurement process for developing the urban water system, based on the analysis. Project preparation (feasibility studies, environmental assessments, etc.) should be pursued simultaneously for enhancing the distribution system, developing the aquifer and building the dam. The city should then execute initial phases of aquifer development and distribution system enhancement, while preparing subsequent phases of those projects. In the meanwhile, decision-

makers should monitor the progress of the mine and how demand evolves in the urban region. If demand grows rapidly and the mine is fully operational in about five years, then the dam should also be executed. This approach conserves valuable time, effort and resources because of simultaneous project preparation and phasing the decision-making process to account for uncertainty in water demand. It also avoids the high stranded costs of building the dam in the event that demand for water is low or the mine is not developed.

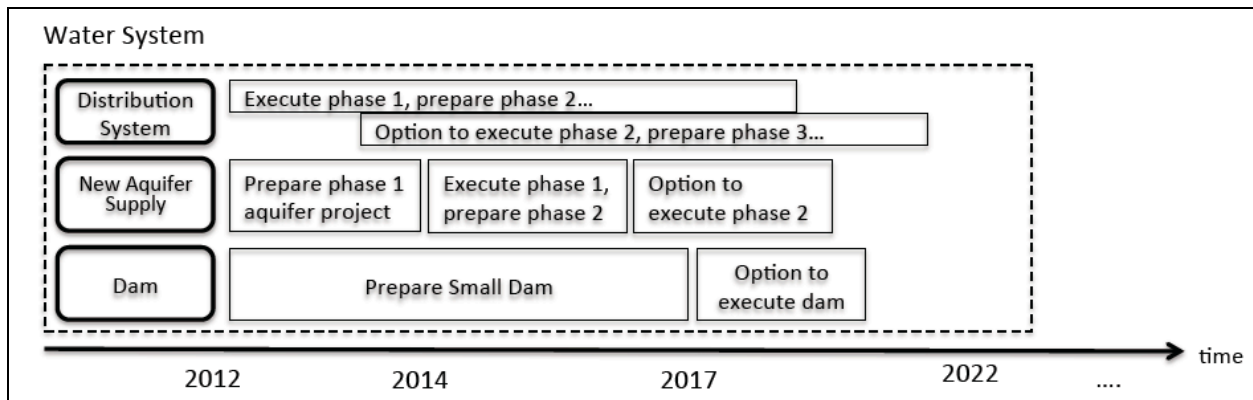


Figure 9. Flexible procurement process for Urban Water System case

5. CONCLUDING REMARKS

The analytical study of the urban water system demonstrates the gains that result from moving away from a deterministic, single-project focus towards a flexible, system view. In the traditional approach to procurement, projects would be evaluated under at most three or four distinct scenarios. Feasibility and safeguard studies for each design strategy would take little account of the findings of studies in other projects. Without the ability to defer an important investment decision such as executing the dam, decision-makers may have selected a design strategy that does little to enhance system value. In contrast, the flexible procurement approach involves proceeding with design studies for variants of projects such as both the small and large dam, budgeting funds for preparatory work on the aquifer development, and putting in place a monitoring process and decision-points for the deferred decision of building the dam.

Implementing a flexible procurement process in development practice calls for prudent management and significant advisory support for the local institutions in charge of delivering large infrastructure projects. This is a final area where the typical development approach lacks flexibility. Budget processes usually allocate far more administrative budget to the period of front-end project preparation for loan or grant approval than to later stage implementation phases, and even the early administrative budget is usually a small share of total administrative costs. However, there are signs this is beginning to change, as development institutions including the World Bank put greater emphasis on delivery and implementation. Culturally, there remains a bias towards projects that are approved fast and disburse funds fast, without more sophisticated governance and implementation arrangements.

Some may be concerned that flexible procurement processes are more complex and impose more requirements on both development organizations and local institutions. For example, one argument is that the analytical demands of performing a study like the one discussed here are too strenuous, and that most project teams lack the capacity to analyze 10,000 demand scenarios. However, a thoughtful exercise up front in narrowing down the variables of interest keeps the analytical demands within bounds. The analytical exercise in our study required only one man-month, after the problem was scoped and defined. It is quite likely that the incremental effort of pursuing a flexible process is offset by important gains in information, conserved budget resources, and a better selection of projects. The gains of more rigorous systems analysis over typical “good, medium and bad” scenario analyses are likely to repay the incremental investment many times over.

The main obstacle to our proposed approach, more than any analytical burden, is the mindset that all important project decisions can and should be made and executed at the outset during initial project approval – at a time when knowledge about the future is most uncertain. Hence, we suggest in closing that the burden of change and increasing sophistication lies as much with the development agencies as the countries procuring infrastructure projects. Implementing flexibility would require changes in their approval processes, in their approach to procurement and safeguards, and even in their accounting procedures. However, flexibility could be incorporated into procurement step by step, simply by allowing

and encouraging multiple parallel studies in large infrastructure projects, together with deferred decision making, and curtailing the reliance on simplistic economic analyses based on forecasts which are “always wrong.” Following such steps in even just a few large projects may substantially alter the long-run gains and risk-return profiles of development projects.

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